antiferromagnetically coupling layer and wherein the separation of said segments defines a physical trackwidth and wherein said biasing layer has a biasing layer thickness, a biasing layer magnetic moment $M_{F2}$ and wherein there is a synthetic coupling energy $J_s$ between said biasing layer and said free layer and wherein said longitudinal biasing layer is antiferromagnetically coupled to said free layer through said antiferromagnetically coupling layer;

a conductive lead layer formed on said ferromagnetic biasing layer; and wherein said free layer thickness and said biasing layer thickness are determined so that the magnetic moment of said free layer, $M_{F1}$, and the magnetic moment of said biasing layer, $M_{F2}$, satisfy the relationship $M_{F2}/ M_{F1} =1$.

**REMARKS:**

When the subject application was filed it was assumed that related patent application HT 01-036/038 would have already been filed. Since the methods disclosed in HT 01-036/038 were to be relied upon as antecedent basis for the method claims 45 and 57 in the present application, HT 01-036/038 was incorporated fully by reference within the present application. However, the present application has been filed before HT 01-036/038, so it is improper to incorporate the latter unfiled application by reference. The purpose of this preliminary amendment as relates to the specifications, therefore, is to include a full description of the material that forms the antecedent basis for the method claims by reading into the specification the material already claimed in method claims 45 and 57 and to eliminate reference to HT 01-036/038. The

specifications had already included a full description of the apparatus claimed in the application, the amendment now incorporates a description of the method by which that apparatus is formed.



The apparatus claims 1 and 22 have been amended to bring them into full agreement with the method claims. In particular, the method claims correctly claim the oxidation of a portion of a biasing layer so as to eliminate it as a ferromagnetic region, while not requiring its actual physical elimination by etching. The apparatus claim had incorrectly omitted the presence of this small oxidized region. The two sets of claims are now in agreement.

Attached hereto is a marked-up version of the changes made in the specifications and in claims 1 and 22 by the current amendment. The attached page is captioned: "**Version with markings to show changes made.**"

It is requested that should there be any problems with this Amendment, please call the undersigned attorney at (845) 452-5863.

Respectfully submitted,

Stephen B. Ackerman, Reg. No. 37,761

**VERSION WITH MARKINGS TO SHOW CHANGES MADE:**

**In the Specifications:**

The following paragraph beginning at line 4 of page 8 is deleted:

[The method by which the sensors described above are fabricated and to which the optimizations also described above can be readily and easily applied is fully disclosed in patent application HT01-063/038, which is incorporated fully herein by reference.]

The following paragraph beginning at line 11 of page 11 is amended as follows:

Referring next to Fig. 3, there is shown a schematic cross-sectional view of the ABS surface of a patterned synthetic exchange longitudinally biased GMR sensor whose structure and method of fabrication are fully described in related patent application HT01-036/038 and which is fully incorporated herein by reference. This structure is similar in many respects to the direct exchange configuration of Fig. 2. except for the antiparallel directions of the F2 and F1magnetic moments M2 (12), M1 (13). It is this configuration of Fig. 3 which, when properly designed and optimized in accord with the simulations of the present invention, constitutes the first embodiment of the present

invention. The following dimensions, however, [are those disclosed in HT01-036/038 and are not] yet in accord with the present invention. As can be seen in Fig. 3, there is first formed an antiferromagnetic pinning layer (40), which can be a layer of antiferromagnetic material chosen from the group of such materials consisting of PtMn, IrMn, NiMn, PdPtMn and FeMn, but which is preferably a layer of PtMn formed to a thickness of 100 angstroms. On this layer is then formed a synthetic antiferromagnetic pinned layer (30), which is a trilayer comprising a first ferromagnetic layer (32), preferably a layer of CoFe formed to a thickness of approximately 15 angstroms, on which is formed a non-magnetic antiferromagnetically coupling layer (34), preferably a layer of Cu formed to a thickness of approximately 18 angstroms, on which is formed a second ferromagnetic layer (36), preferably a layer of CoFe formed to a thickness of approximately 20 angstroms. On the pinned layer is then formed a non-magnetic spacer layer (31), which is preferably a layer of Cu approximately 18 angstroms thick. On this spacer layer is then formed a ferromagnetic free layer (27), which is a bilayer comprising a CoFe layer of preferred thickness 10 angstroms, on which is formed an NiFe layer of preferred thickness 20 angstroms. The remaining layers deposited to complete the formation will not have their thicknesses specified at this point, since the preferred values of those thicknesses will depend on the application of the results of this invention and will be specified in conjunction with the discussion of Fig. 8, below. On the free layer is then formed a non-magnetic antiferromagnetically coupling layer (28), which can be a layer of either Rh or Ru of proper thickness to provide the antiferromagnetic exchange coupling with the biasing layer to be formed. On the coupling layer is formed a ferromagnetic biasing layer (25), preferably a layer of CoFe. On the ferromagnetic

biasing layer is formed an antiferromagnetic pinning layer, preferably a layer of IrMn of approximately 40 angstroms thickness. Finally, a conducting lead layer (20) is formed on the pinning layer. At this stage of the fabrication two magnetic annealing processes are carried out, the first being to set the transverse magnetization of the pinned layer (30) and the second being to set the longitudinal magnetization of the free (27) and biasing (25) layers. Following these annealing processes, the physical trackwidth region (10) is formed by a sequence of etches and oxidation processes which leaves the conducting leads (20), the antiferromagnetic pinning layer (25) and the ferromagnetic biasing layer (25) in a patterned configuration. The first etching process is an ion beam etch, which removes the conducting lead layer (20) and the antiferromagnetic pinning layer (29) beneath it in the trackwidth region. A subsequent plasma etch then oxidizes the ferromagnetic biasing layer (25), destroying, thereby, its ferromagnetic properties within the trackwidth region, but leaving it physically present as a layer of oxide (45), which is shown unshaded. The physical trackwidth (10) of this configuration is approximately 0.1 microns and is defined by the width of the region between the leads (20) and patterned biasing (25) layers (F2). Typically, F2 is a layer of CoFe whose thickness is approximately 15 angstroms. Because the ferromagnetic free layer (F1) (27) extends the entire width of the sensor, it is not adversely affected by the strength of the biasing layer as in the case of the hard biased abutted junction of Fig. 1. Typically F1 is a CoFe/NiFe bilayer, wherein the thickness of the CoFe is approximately 10 angstroms and the thickness of the NiFe layer is approximately 20 angstroms. The diagram also shows the antiferromagnetic layer (29), typically a layer of IrMn, of thickness approximately approximately 40 angstroms, which pins the F2 biasing layer (25). Unlike the

configuration of Fig. 2, the free layer F1 (27) is separated from the biasing layer F2 (25) by a non-magnetic coupling layer (28) which is typically a layer of Cu, Rh or Ru and which has the correct thickness to exchange couple the ferromagnetic free layer (27) to the ferromagnetic biasing layer (25) by antiferromagnetic coupling. A layer of Ru of approximately 7.5 angstroms thickness, for example, is preferable. The remainder of this configuration is the same as in Fig. 2. The strength of the antiferromagnetic coupling (the pinning field) is stronger than the ferromagnetic coupling in Fig. 2 and is typically over 700 Oe. According to our simulations a physical trackwidth of 0.1 microns in the above configuration will produce an effective trackwidth of 0.15 microns because of the undesirable side reading. It is to be noted that the layer thicknesses given above refer to a prior art configuration as does the 0.15 micron effective trackwidth for a 0.1 micron physical trackwidth. Only with the use of the method of the present invention will the significant reduction in effective trackwidth and reduced side reading be obtained. The present invention will provide a novel mechanism for optimizing the thicknesses of F1 and F2 so as to appreciably narrow the effective trackwidth for a given physical trackwidth.

The following paragraph beginning at line 16 of page 13 is amended as follows:

Referring next to Fig. 4, there is shown a schematic cross-sectional view of the ABS surface of a patterned synthetic exchange biased GMR sensor, whose novel configuration provides the second preferred embodiment of this invention. [Although the general] <u>The</u> configuration <u>and its method of formation</u> is similar in [some] <u>all</u> respects to

the patterned synthetic exchange configuration of Fig. 3, [there is an] with the important difference [in] that the biasing layer F2 (25) is not pinned by an antiferromagnetic layer (layer (29) in Fig. 3). The omission of antiferromagnetic layer simplifies the fabrication process of the sensor, improves its topography and, most significantly, makes the magnetostriction characteristics negative. In the absence of the antiferromagnetic pinning layer the exchange energy term, $J_{ex}$, is zero and the optimization formula becomes:

$$M_{F2}/M_{F1}=(J_s+J_{ex})/J_s ==(J_s+0)/J_s =1,$$

which leads to an optimized thickness ratio, $F_2/F_1$, which is also 1. The F2 biasing layer (25) can be a layer of ferromagnetic material such as CoFe.

Please amend the following paragraph beginning at line 8 of page 18 as follows:

Referring now to Fig. 8 there is shown the first preferred embodiment of this invention, which is the formation of the structure in Fig. 3, using [fabrications methods from related patent application HT01-032 fully incorporated herein by reference] the method of formation described in connection with the discussion of Fig. 3 and, in addition, applying the results of the simulations described in Fig's 5-7, Tables 1 and 2 and the formula $M_{F2}/M_{F1} =( J_s + J_{ex})/ J_s$. In Fig. 8 there is shown, therefore, the structure of Fig. 3, wherein the dimensions of the F1 and F2 layers and their material composition are as follows. It is further understood that if the objects and advantages of the present invention are to be obtained, the determination of F2 and F1 dimensions must be calculated anew for each choice of their material composition and the values of $J_s$ and $J_{ex}$ resulting from the various possible coupling layers and pinning layers. In the present

figure, however, the free layer (27) is a bilayer of CoFe/NiFe, wherein the CoFe (21) has a thickness between approximately 3 and 20 angstroms, with 10 angstroms being the preferred value and the NiFe (22) has a thickness between 40 and 10 angstroms, with 20 angstroms being the preferred value. Within this range of values, the biasing layer, F2, (27) is a layer of CoFe of thickness range between approximately 22 angstroms and 34 angstroms, with 28 angstroms being the preferred value and the non-magnetic coupling layer (28) is a layer of Ru of thickness between approximately 2 angstroms and 9 angstroms, with 7.5 angstroms being preferable. Alternatively, if the non-magnetic coupling layer (28) is a layer of Rh of thickness between approximately 3 and 6 angstroms, with 5 angstroms being preferable, the F2 layer (27) would be a layer of CoFe of thickness between approximately 18.6 angstroms and 26.6 angstroms, with 22.6 angstroms being preferable. The pinning layer of IrMn (29) is in the thickness range between approximately 25 angstroms and 100 angstroms. In the second embodiment, which would be the application to the structure of Fig. 4 the relationship $M_{F2}/M_{F1} = 1$, the optimization the dimensional ranges of layer F1 remain approximately the same as in the first embodiment, while the thickness of the F2 layer, which is a layer of CoFe, is between approximately 10 angstroms and 20 angstroms with 15 angstroms being preferred. All other layers and dimensions would be the same as those of Fig. 3.

**In the claims:**

Please amend claim 1 as follows:

1. A synthetic, patterned, longitudinally exchange biased GMR sensor with narrow effective trackwidth and reduced side reading comprising:

a substrate;

a first layer of antiferromagnetic material formed on the substrate, said layer being a pinning layer;

a synthetic antiferromagnetic pinned layer formed on said antiferromagnetic pinning layer;

a non-magnetic spacer layer formed on said pinned layer;

a ferromagnetic free layer formed on said non-magnetic spacer layer, said free layer having a free layer thickness and a free layer magnetic moment M1;

a non-magnetic antiferromagnetically coupling layer formed on said ferromagnetic free layer;

a patterned, [ferromagnetic,] longitudinal biasing layer formed on said coupling layer, <u>said biasing layer being formed in three segments:</u> [as] two discrete, disconnected and laterally separated <u>ferromagnetic</u> segments <u>and a central portion between and continuous with said segments that has been rendered non-magnetic by an oxidation process, and wherein said ferromagnetic segments are</u>[,] laterally and symmetrically disposed to either side of the antiferromagnetically coupling layer and wherein the separation of said segments defines a physical trackwidth and wherein said biasing layer has a biasing layer thickness, a biasing layer magnetic moment M2 and wherein there is a synthetic coupling energy $J_s$ between said biasing layer and said free layer and wherein said longitudinal biasing layer is antiferromagnetically coupled to said free layer through said antiferromagnetically coupling layer;

a second antiferromagnetic layer formed on said patterned, longitudinal biasing layer and coexstensive with it, said second antiferromagnetic layer being exchange coupled to said longitudinal biasing layer and there being an exchange energy, $J_{ex}$, between said second antiferromagnetic layer and said biasing layer;



a conductive lead layer formed on said antiferromagnetic layer; and wherein said free layer thickness and said biasing layer thickness are determined so that the magnetic moment of said free layer, $M_{F1}$, and the magnetic moment of said biasing layer, $M_{F2}$, satisfy the relationship $M_{F2}/M_{F1} =( J_s + J_{ex})/ J_s$.

Please amend claim 22 as follows:

22. A synthetic, patterned, longitudinally exchange biased GMR sensor with narrow effective trackwidth and reduced side reading comprising:

a substrate;

a first layer of antiferromagnetic material formed on the substrate, said layer being a pinning layer;

a synthetic antiferromagnetic pinned layer formed on said antiferromagnetic pinning layer;

a non-magnetic spacer layer formed on said pinned layer;

a ferromagnetic free layer formed on said non-magnetic spacer layer, said free layer having a free layer thickness and a free layer magnetic moment M1;

a non-magnetic antiferromagnetically coupling layer formed on said ferromagnetic free layer;

a patterned, [ferromagnetic,] longitudinal biasing layer formed on said coupling layer, <u>said biasing layer being formed in three segments:</u> [as] two discrete, disconnected and laterally separated <u>ferromagnetic</u> segments <u>and a central portion between and continuous with said segments that has been rendered non-magnetic by an oxidation process, and wherein said ferromagnetic segments are</u>[,] laterally and symmetrically disposed to either side of the antiferromagnetically coupling layer and wherein the separation of said segments defines a physical trackwidth and wherein said biasing layer has a biasing layer thickness, a biasing layer magnetic moment M2 and wherein there is a synthetic coupling energy $J_s$ between said biasing layer and said free layer and wherein said longitudinal biasing layer is antiferromagnetically coupled to said free layer through said antiferromagnetically coupling layer;

a conductive lead layer formed on said ferromagnetic biasing layer; and wherein said free layer thickness and said biasing layer thickness are determined so that the magnetic moment of said free layer, $M_{F1}$, and the magnetic moment of said biasing layer, $M_{F2}$, satisfy the relationship $M_{F2}/M_{F1} = 1$.